MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2015/2016

ENT3056 – ADVANCED FABRICATION TECHNOLOGY

(NE)

09 MARCH 2016
09:00 a.m. - 11:00 a.m.
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question paper consists of 8 pages with 4 Questions only.
2. Attempt **ALL FOUR** questions. All questions carry equal marks and the distribution of the marks for each question is given.
3. Please print all your answers in the Answer Booklet provided.
4. Please refer to APPENDIX on page 7 and 8 for a list of physical constants, a list of formulas, and the error function table.

QUESTION 1

(a) Compliment the advantages of silicon (Si) as compared to germanium (Ge) and gallium arsenide (GaAs), which make Si the overwhelming key material in the microelectronic industries. [4 marks]

(b) With schematic aids, discuss the characteristics of the Czochralski (CZ) process in the growth of semiconductor single crystal. [2+9 marks]

(c) In a CZ process, a boule of single crystal Si doped with boron is pulled from the melt. After the boule is pulled, it is sliced into wafers. The wafer taken from the top of the boule has a boron concentration of 3.5×10^{14} cm^{-3}. The segregation coefficient (k) for boron is given as 0.8. Determine the doping concentration of the wafer taken from the position corresponding to 85 % of the initial charge solidified. [5 marks]

(d) Sputter deposition and thermal evaporation are physical vapor deposition (PVD) methods of metallization for microelectronic integrated circuits. Describe the advantages of sputtering process compared to evaporation process. [5 marks]

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QUESTION 2

(a) Diffusion and ion implantation process are techniques used to introduce dopants in order to create n- and p-well regions as well as drain and source doped regions in the semiconductor wafers. Discuss the advantages of ion implantation process over the diffusion process. [10 marks]

(b) Explain the ion channeling effect in the ion implantation process for a crystalline wafer. Propose techniques to overcome this effect. [2+3 marks]

(c) During ion implantation process, the implanted ions with high kinetic energy will lead to damage in the semiconductor wafer. Distinguish the damage profile in the semiconductor wafers due to light ions and heavy ions employed in the process, respectively. [5 marks]

(d) A 40 keV implant of phosphorus is done onto the bare silicon wafer. The projected range of the implanted profile is 1100 Å. Take the standard deviation of the projected range as 450 Å.

(i) Find the depth of peak of the implanted profile. [1 mark]
(ii) Find the peak concentration for dose of 10^{11} cm^{-2}. [4 marks]

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QUESTION 3

(a) Illustrate the optical setup for a projection aligner system with appropriate labels. Describe the advantages and disadvantages of the projection aligner system in optical lithographic patterning process? [2+4 marks]

(b) With a resist constant, k, of 0.7 and a numerical aperture, NA, of 0.28, determine the minimum device structure size achievable with a projection aligner system using exposure wavelengths of 80, 110, 160, 220 and 320 nm, respectively. Propose the suitable exposure wavelengths for the fabrication of devices with structure sizes smaller than 400 nm features. [4 marks]

(c) Describe the role of etch process in the fabrication of integrated circuits (ICs). Identify two types of etching processes used in the ICs fabrication. [3 marks]

(d) Given a silicon wafer with wafer thickness of 500 μm. A wet etching process is performed on the silicon wafer with the purpose to etch through the wafer. The etchant consists of a mixture of two parts of $HC_2H_3O_2$, two parts of 49.2 % HF and six parts of 69.5 % HNO_3. Determine the required duration for the etching process to etch through the wafer. The etch rate curve of silicon is given in Figure 3(d) below. [2 marks]

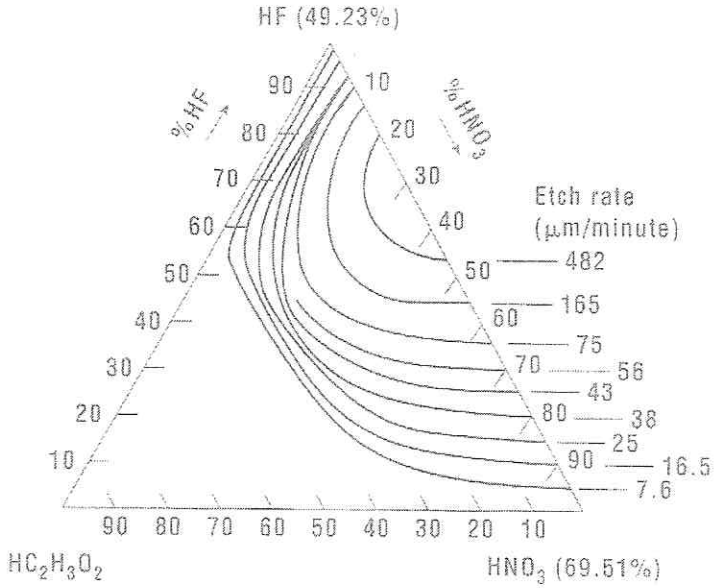

Figure 3(d)

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QUESTION 3

(e) Figure 3(e) below depicts a thermally oxidized silicon wafer, which is spin coated with photoresist and then exposed with ultraviolet light through an optical mask.

(i) Sketch the final pattern of the oxide structure following the positive and negative photoresist, respectively. [2 marks]

(ii) Describe the advantages and disadvantages of the positive and negative photoresists. [2 marks]

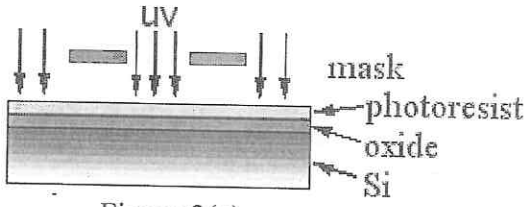

Figure 3(e)

(f) Figure 3(f) shows the cross sectional view of a screen-printed silicon solar cell. With schematic aids, design necessary processing steps to fabricate this solar cell, starting from a p-type silicon wafer. State clearly each step in sequence. [6 marks]

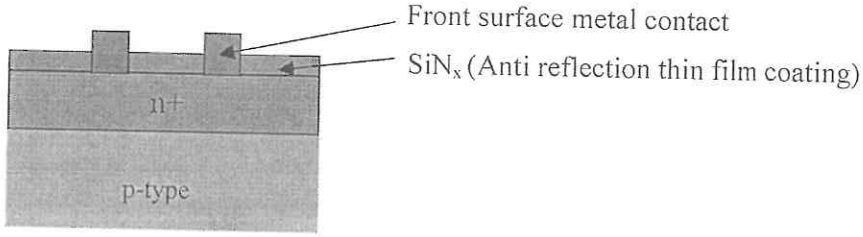

Figure 3(f)

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QUESTION 4

(a) In an ideal situation, the metal layers make contact with the semiconductor layer without adding parasitic resistance into the contact. In reality, however, contact resistance is always present.

(i) Describe the influence of the contact resistance on the performance of the device having metal-semiconductor contact. [2 marks]

(ii) Suggest a way to minimize the contact resistance. [2 marks]

(iii) Relate the contact resistance, R_c, and specific contact resistivity, ρ_c, in an mathematical expression. [2 marks]

(iv) Given a specific contact resistivity, ρ_c, of 1.5 $\mu\Omega$ cm^2, estimate the contact resistance for the following contacts:

- a 0.5x0.5 $(\mu m)^2$ contact [2 marks]
- a 1.5x1.5 $(\mu m)^2$ contact [2 marks]

(b) Copper (Cu) metallization has been tipped as alternative metallization scheme to aluminum (Al) metallization especially for ultra large scale integrated (ULSI) technology.

(i) Describe the reason why Cu is preferred over Al. [2 marks]

(ii) What is the main obstacle for the implementation of Cu metallization scheme? Describe a solution to overcome this obstacle. [6 marks]

(iii) A copper interconnect has a contact area of 3 μm by 3 μm. Determine the maximum current permissible to flow in this conductor if the maximum current density is 2 x 10^5 A/cm^2? [3 marks]

(c) Distinguish the properties of an Ohmic contact and a Schottky contact. [4 marks]

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APPENDIX **Physical Constants:**

Avogadro number, $N_{avo} = 6.02217\times10^{23}$ mol^{-1}
Boltzmann constant, $k = 1.380622\times10^{-23}$ J K^{-1} $= 8.61712\times10^{-5}$ eV K^{-1}
Electronic charge, $e = 1.60219\times10^{-19}$ C
Electron rest mass, $m_o = 9.10956\times10^{-31}$ kg
Electron volt, 1 eV $= 1.60219\times10^{-19}$ J
Si yield strength $= 2\times10^{7}$ dynes cm $= 7$ GPa
Latent heat of fusion for Si, L = 340 cal g^{-1}
Thermal conductivity of Si, k = 0.21 W cm^{-1} °C^{-1}
Amount of heat of 1 calorie = 4.14 J
Density of bulk Si = 2.33 g cm^{-3}
Density of molten Si = 2.53 g cm^{-3}
Electric current of 1 A = 1 Cs^{-1}
Atomic mass unit of 1 amu $= 1.66053\times10^{-27}$ kg
Magnetic flux density of 1 T = 1 Wb m^{-2} $= 10^{4}$ G
Angstrom unit of 1 Å $= 1\times10^{-10}$ m $= 0.1$ nm $= 1\times10^{-4}$ μm
Permittivity of free space $= 8.85\times10^{-14}$ F cm^{-1}
Pressure of 1 Torr = 133.32237 Pa

Formulas:

$\phi = \dfrac{P}{\sqrt{2\pi mkT}}$	$N(x) = \dfrac{Q_o}{\sqrt{2\pi}\Delta R_p} e^{\left[-\frac{1}{2}\left(\frac{x-R_p}{\Delta R_p}\right)^2\right]}$
$\lambda = \dfrac{kT}{\sqrt{2}\,\pi P d^2}$	$N(x,y) = \dfrac{N(x)}{\sqrt{2\pi}\Delta R_\perp} e^{\left[-\frac{y^2}{2\Delta R_\perp{}^2}\right]}$
$R = \sqrt{\dfrac{m}{2\pi k\rho^2}}\,\dfrac{P}{\sqrt{T}}\,\dfrac{A}{4\pi r^2}$	$C_s = \dfrac{Q}{\sqrt{\pi Dt}}$
$RC = \dfrac{R_s L^2 \in_{gd}}{d_{gd}} = \dfrac{\rho}{d_{poly-si}}\,\dfrac{L^2 \in_{gd}}{d_{gd}}$	$Q = 2C_s\sqrt{\dfrac{Dt}{\pi}}$
$C(x,t) = C_s erfc\left[\dfrac{x}{2\sqrt{Dt}}\right]$	$Q = \sqrt{2\pi}N_p\Delta R_p$
$C(x) = \dfrac{Q}{\sqrt{\pi Dt}} e^{-\left(\frac{x}{2\sqrt{Dt}}\right)^2}$	$C = k\,C_0\,(1-x)^{k-1}$
$W_{min} = k\,\{\lambda / NA\}$	$W_{\min} = \sqrt{k\lambda g}$
$R_c = \rho_c / A$ $\qquad \rho = Rs \cdot t$	$k_0 = \dfrac{C_s}{C_l}$

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Values of the error function $\operatorname{erf}(t) = \frac{2}{\sqrt{\pi}} \int_0^t e^{-a^2}\, da$

t	0	1	2	3	4	5	6	7	8	9
0.0	0.000	0.0113	0.0226	0.0338	0.0451	0.0564	0.0676	0.0789	0.0901	0.1013
0.1	0.1125	0.1236	0.1348	0.1459	0.1569	0.1680	0.1790	0.1900	0.2009	0.2118
0.2	0.2227	0.2335	0.2443	0.2550	0.2657	0.2763	0.2869	0.2974	0.3079	0.3183
0.3	0.3286	0.3389	0.3491	0.3593	0.3694	0.3794	0.3893	0.3992	0.4090	0.4187
0.4	0.4284	0.4380	0.4475	0.4569	0.4662	0.4755	0.4847	0.4937	0.5027	0.5117
0.5	0.5205	0.5292	0.5379	0.5465	0.5549	0.5633	0.5716	0.5798	0.5879	0.5959
0.6	0.6039	0.6117	0.6194	0.6270	0.6346	0.6420	0.6494	0.6566	0.6638	0.6708
0.7	0.6778	0.6847	0.6914	0.6981	0.7047	0.7112	0.7175	0.7238	0.7300	0.7361
0.8	0.7421	0.7480	0.7538	0.7595	0.7651	0.7707	0.7761	0.7814	0.7867	0.7918
0.9	0.7969	0.8019	0.8068	0.8116	0.8163	0.8209	0.8254	0.8299	0.8342	0.8385
1.0	0.8472	0.8468	0.8508	0.8548	0.8586	0.8624	0.8661	0.8698	0.8733	0.8768
1.1	0.8802	0.8835	0.8868	0.8900	0.8931	0.8961	0.8991	0.9020	0.9048	0.9076
1.2	0.9103	0.9130	0.9155	0.9181	0.9205	0.9229	0.9252	0.9275	0.9297	0.9319
1.3	0.9340	0.9361	0.9381	0.9400	0.9419	0.9438	0.9456	0.9473	0.9490	0.9507
1.4	0.9523	0.9539	0.9554	0.9569	0.9583	0.9597	0.9611	0.9624	0.9637	0.9649
1.5	0.9661	0.9673	0.9684	0.9695	0.9706	0.9716	0.9726	0.9736	0.9746	0.9755
1.6	0.9764	0.9772	0.9780	0.9789	0.9796	0.9804	0.9811	0.9818	0.9825	0.9832
1.7	0.9838	0.9844	0.9850	0.9856	0.9861	0.9867	0.9872	0.9877	0.9882	0.9886
1.8	0.9891	0.9895	0.9899	0.9904	0.9907	0.9911	0.9915	0.9918	0.9922	0.9925
1.9	.99279	.99309	.99338	.99366	.99392	.99418	.99443	.99466	.99489	.99511
2.0	.99532	.99552	.99572	.99591	.99609	.99626	.99642	.99658	.99673	.99688
2.1	.99702	.99715	.99728	.99741	.99753	.99764	.99775	.99785	.99795	.99805
2.2	.99814	.99822	.99831	.99839	.99846	.99854	.99861	.99867	.99874	.99880
2.3	.99886	.99891	.99897	.99902	.99906	.99911	.99915	.99920	.99924	.99928
2.4	.99931	.99935	.99938	.99941	.99944	.99947	.99950	.99952	.99955	.99957
2.5	.99959	.99961	.99963	.99965	.99967	.99969	.99971	.99972	.99974	.99975
2.6	.99976	.99978	.99979	.99980	.99981	.99982	.99983	.99984	.99985	.99986
2.7	.99987	.99987	.99988	.99989	.99989	.99990	.99991	.99991	.99992	.99992
2.8	.99992	.99993	.99993	.99994	.99994	.99994	.99995	.99995	.99995	.99996
2.9	.99996	.99996	.99996	.99997	.99997	.99997	.99997	.99997	.99997	.99998
3.0	.99998	.99998	.99998	.99998	.99998	.99998	.99998	.99999	.99999	.99999

for $t > 3$ $\quad \operatorname{erf}(t) \approx 1 - \frac{1}{\sqrt{\pi}\, t} \exp\left(-t^2\right)$

erfc (t) = 1 - erf (t)

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